2.7 Consolidation Test

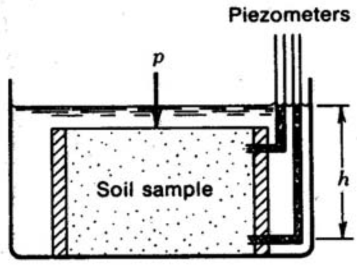
2.7.1 General

- Consolidation can be defined as a dissipation process of excess pore pressure induced by applied load or change of boundary conditions.

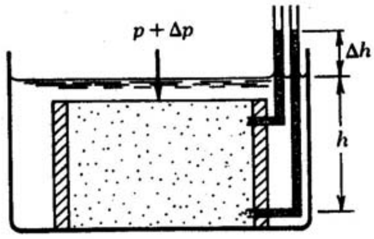
- It is a time dependent behavior of soil deformation.
  ⇒ Significant in **saturated clayey soils**.
  ⇒ Factors on consolidation time
    1) Degree of saturation
    2) Coefficient of permeability of soil
    3) Viscosity and compressibility of the pore fluid
    4) **Length of path the expelled pore fluid must take to find equilibrium**.
    5) Compressibility of soils

- Consolidation test determines parameters for the time dependent behavior of soils.
  1) The amount of deformation ⇒ (Primary) Consolidation settlement (+ Secondary compression settlement)
  2) Rate of consolidation (i.e. Consolidation time)

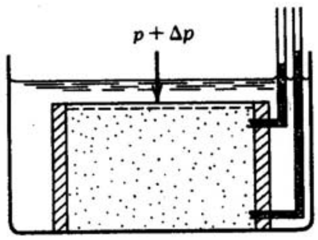
- Idealized stages in primary consolidation



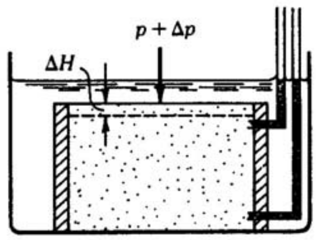
(*a*) Piezometers have reached static equilibrium under some compressive load p.



(*b*) On adding a load increment Δp the piezometers record a hydrostatic pressure increase of Δh as shown. There is often some finite time lag before Δh is fully developed but Δh is considered instantaneous in any idealization.



(*c*) Relative positions of piezometers some time after application of Δp. With shorter flow path the upper piezometer loses head faster than the bottom one.



(*d*) At end of primary consolidation under pressure increment Δp both piezometers have returned to the initial position of "*a*." Secondary compression will continue under Δp for some additional time so that the final total settlement will be larger than the ΔH at the end of primary consolidation.

Figure 13-2
Stages in primary consolidation (idealized).

- Consolidation theory follows Darcy's law.

  $v = ki = k(\Delta h/L) \quad \Rightarrow \quad \Delta t = L/v = L/\{k(\Delta h/L)\} = \mathbf{L^2/(k\Delta h)}$

  ⇒ Doubling L requires 4 times for consolidation.

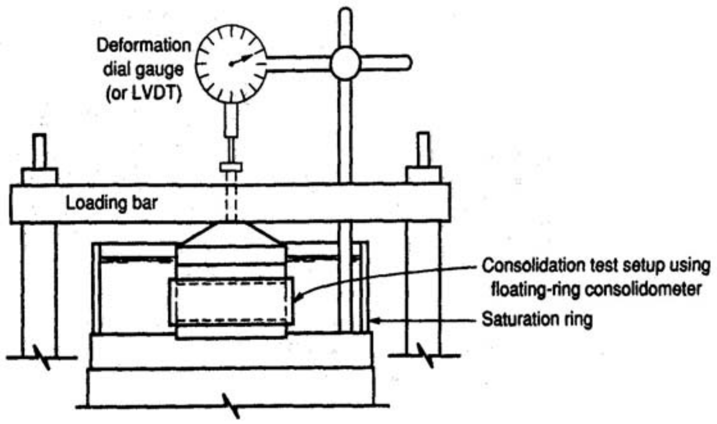
  ⇒ Consolidation rate is getting slower with decreasing Δh as time passes.

2.7.2 <u>Consolidation Test</u>

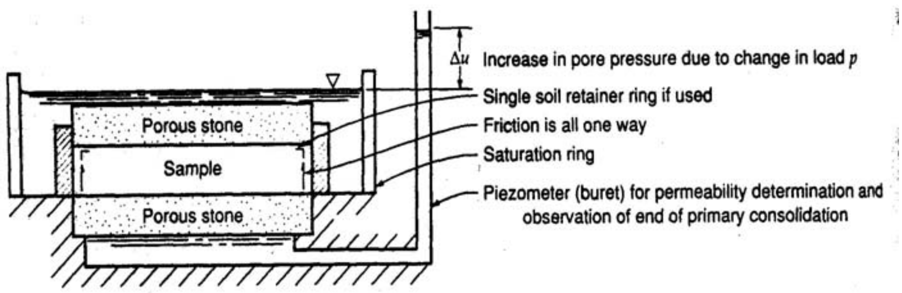
- Simulates 1-dimensional state (flow and deformation)

  ⇒ Using a circular metal ring (the fixed-ring type or floating-ring type) confining the sample.

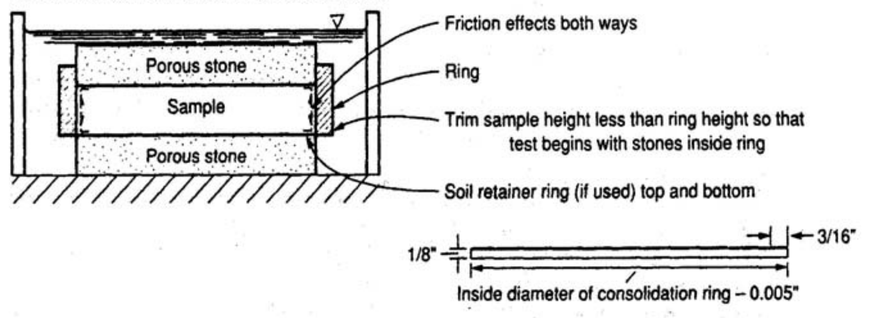
  ⇒ Possible to measure the pore pressure during consolidation and to perform the permeability tests in the oedometer.



(a) Consolidometer.



(b) Fixed-ring consolidometer. May be used to perform a falling-head permeability test by attaching a buret to the piezometer outlet at base. Fill buret with water to level h_1 and at some time interval measure h_2 as in Test 12. Remove and drain buret for next load increment.



(c) Floating-ring consolidometer.

Figure 13-3
Select line details of a consolidation test.

- Sample size : 20 – 40 mm thickness(H) and 45 – 113 mm diameter(D).
  D/H > 2.5 and D < (Tube sample) - 6mm.
  (Commonly used sample size : D = 63.5mm, H= 25.4mm)

- Ring-to-soil friction problems:
  ⇒ Should be reduced by limiting sample thickness, spraying the inner ring wall with tefron powder or using a tefron-lined ring.

- Equipment calibration
  ⇒ Check the compressibility of load block and porous stones, if necessary.

- A loading sequence and measurements
  1) A loading sequence
  * Applying loads with a load ratio $\Delta p/p$ = 1 in general, such as (5, 10), 20, 40, 80, 160, 320, 640 … etc., kPa with at least 1 unload-reload cycle (after reaching maximum past pressure, p_{max})
  (unload → 2 steps $(\frac{1}{2}p_{max}, \frac{1}{8}p_{max})$)
  * Each load is sustained for one day (24 hrs)
  * The specimen is kept under water throughout the test.
  2) Measurements
  * Measuring vertical deformation from dial gage or LVDT with time. (Vertical strain, volumetric strain, change of void ratio)
  Dial gage reading × Calibration factor = Vertical deformation (ΔH)
  ⇒ Vertical strain $\varepsilon_{vertical}$ (= volumetric strain, ε_{volume}) = $\Delta H/H_o$
  ⇒ Change of void ratio, $\Delta e = (1+e_o)\ \varepsilon_{vertical}$
  * Take a dial gage reading at time sequence for each load as below (example)
  8sec, 15sec, 30sec, 1min, 2min, 4min, 8min, 15min, 30min, 1hr, 2hr…

2.7.3 Evaluating consolidation parameters from consolidation test

Typical plot of the test results

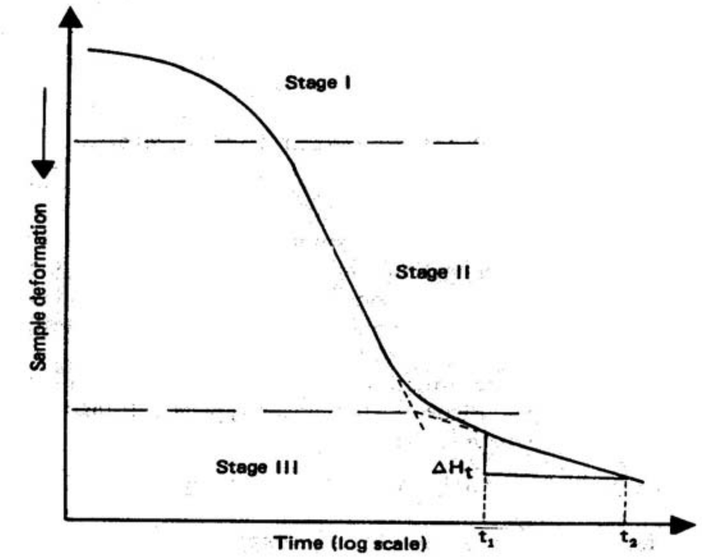


Fig. ΔH vs. t (log scale) for each load increment

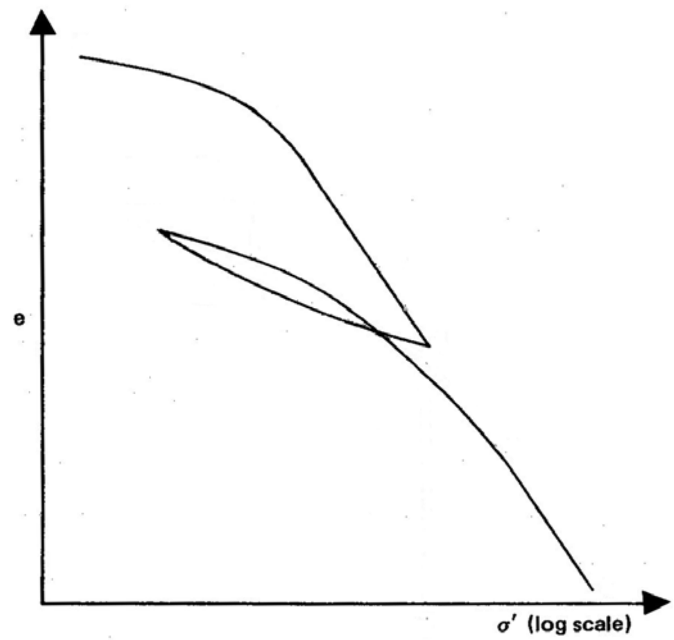


Fig. e vs. σ' (log scale)

1) Parameters for time dependent behavior.

- The coefficient of consolidation (c_v) and the secondary compression coefficient (c_α)
- From Terzaghi's 1-dimensional consolidation theory

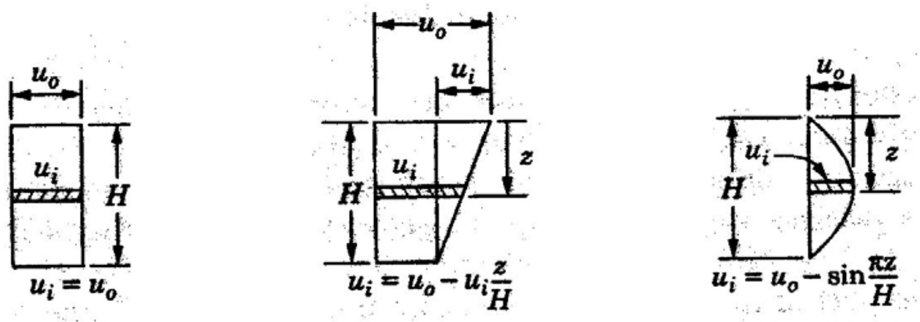
$$T_i = \frac{c_v t_i}{H_d^2} \quad \text{and} \quad c_v = \frac{T_i H_d^2}{t_i}$$

where T_i = time factor given in Table 13.1

t_i = corresponding time for T_i

H_d = the longest drainage path

Table 13-1 Time factors for indicated pressured distribution



Case I Case Ia Case II

Pore-pressure distribution for case I usually assumed for case Ia.

U, %	Case I	Case II
0	0.000	0.000
10	0.008	0.048
20	0.031	0.090
30	0.071	0.115
40	0.126	0.207
50	0.197	0.281
60	0.287	0.371
70	0.403	0.488
80	0.567	0.652
90	0.848	0.933
100	∞	∞

i) Logarithm-of-time method

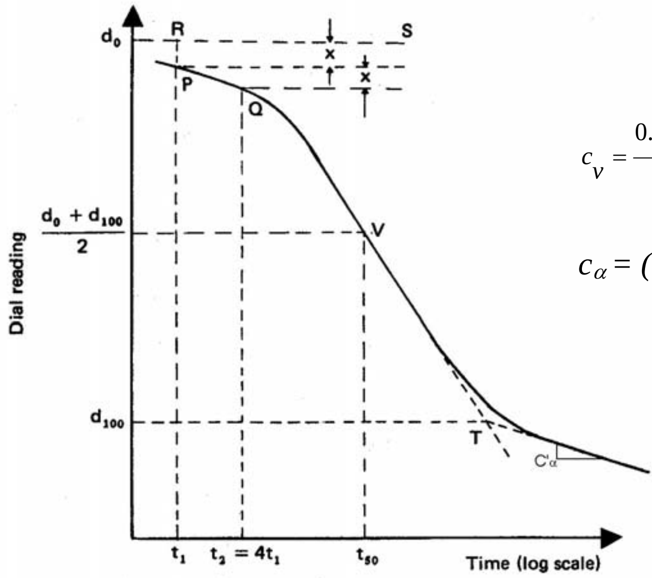


Fig. 5.37 Logarithm-of-time method for determination of C_v.

$$c_v = \frac{0.197 H_d^2}{t_{50}}$$

$$c_\alpha = (1+e_o)c_\alpha'$$

ii) Square-root-time method

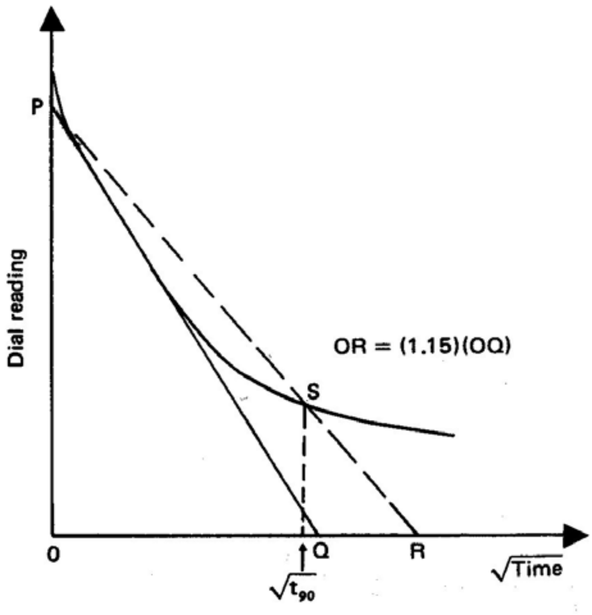


Fig. 5.38 Square-root-of-time method for determination of C_v.

$$c_v = \frac{0.848 H_d^2}{t_{90}}$$

2) Deformation parameters.

- The compressive index (C_c), the recompression (or swelling) index (C_r), and the preconsolidation pressure (or maximum past pressure) (p_{max})

i) The preconsolidation pressure (p_{max})

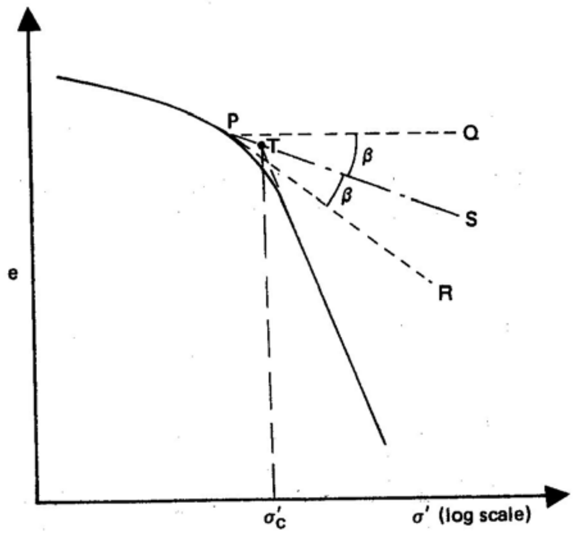


Fig. 5.32 Graphical procedure for determination of preconsolidation pressure.

ii) The compressive index (C_c), and the recompression (or swelling) index (C_r)

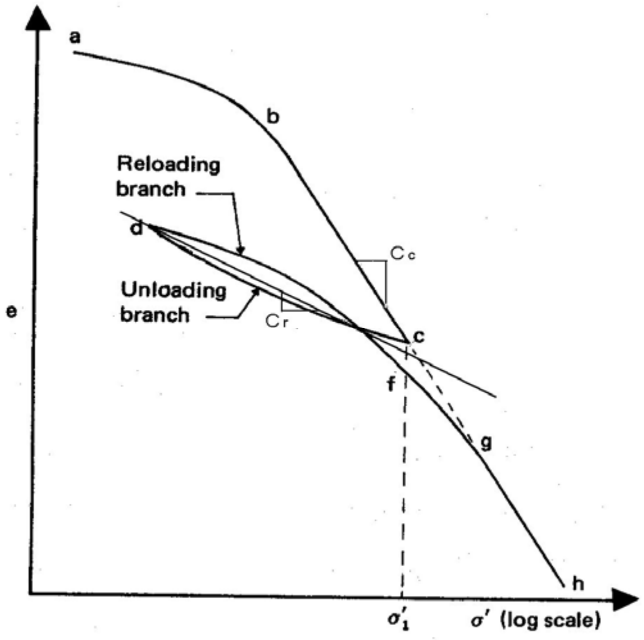


Fig. 5.31 Plot of void ratio vs. effective pressure showing unloading and reloading branches.

- $C_c = (1+e_o)C_c'$ and $C_r = (1+e_o)C_r'$
- Note : C_c', C_r' and c_α' is related to dial reading or volumetric(vertical) strain.

  C_c, C_r and c_α is related to void ratio e.